

# A Pitching Foil with a Flexible Flap Creates an Orderly Jet

Sachin Y. Shinde and Jaywant H. Arakeri

Department of Mechanical Engineering,  
Indian Institute of Science, Bangalore-560012, India

October 19, 2010

The wing-flexibility of flying birds and insects is one important reason, among the others, for high lift generation during hovering [1]. Inspired by this observation, we experimentally studied the effect of chordwise flexibility on the flow generated by flapping foil in the quiescent fluid.

To mimic wing-flexibility, a flexible flap with negligible mass and stiffness is attached at the trailing edge of NACA0015 airfoil that oscillates sinusoidally at a fixed location in quiescent water in a glass tank. The airfoil is confined between the end-plates to ensure two-dimensionality of the flow. The airfoil model is oscillated by a servo motor about a hinge point at 30% chord from the leading edge. The dimensions of the airfoil are: chord 40 mm and span 100 mm. The flap length is 75% of the rigid chord length; the flap is 100 mm in spanwise direction. The flap is made from 0.05 mm thick Polythene sheet; its Young's modulus ( $E$ ) is  $3.02 \times 10^8$  N/m<sup>2</sup> and flexural rigidity ( $EI$ ) is  $3.15 \times 10^{-7}$  Nm<sup>2</sup>. We visualize the flow with Polystyrene particles and measure velocities using particle image velocimetry (PIV). The parameters that were varied were frequency and amplitude of oscillation. The flow is studied for 12 cases: three amplitudes of oscillation,  $\pm 10^\circ$ ,  $\pm 15^\circ$ ,  $\pm 20^\circ$ , and four frequencies for each amplitude, 1, 2, 3 and 4 Hz. The experiments were conducted with two airfoil models: one with flexible flap and the other without flap.

We observed that sinusoidal pitching of the airfoil without flap i.e. with sharp, rigid trailing edge in still water produces a divergent, weak jet that meanders randomly about the mean-position, in all the 12 cases. On the contrary, the airfoil with flexible flap creates a narrow, coherent, non-meandering,

undulating jet with the vortices staggered in the form of a ‘reverse Karman vortex street’, for most of the cases studied. The non-meandering, orderly jet produced by airfoil with flexible flap stays nearly along the mean-position line. The flow generation mechanism is as follows. The water is drawn-in by the rigid foil as well as flexible flap from the front and mainly from the sides towards the airfoil model and given momentum and energy in a highly directional manner to form the jet. The flap undergoes large deformations and plays very important role in keeping proper spacing among the vortices by shedding them at appropriate points and phases such that they are sustained far downstream.

The major differences between the flows produced by the two airfoil models suggest that the flexibility of flap is crucial in the production of such an orderly jet. But, one important question arises i.e. does the airfoil with flexible flap always produce an orderly jet? It has been observed that the foil with flexible flap does not produce an orderly jet for the extreme cases in the parameter set. Effective stiffness of the flap reduces and it becomes more flexible with increase in amplitude and frequency of oscillation. The flexible foil produces a jet that meanders about the mean-position line for amplitude  $\pm 10^\circ$  and frequency 1 Hz where the flap is relatively stiff, and, it produces a jet that blooms and spreads in the downstream region for amplitude  $\pm 20^\circ$  and frequency 4 Hz where the flap is effectively very flexible. Thus, the creation of narrow, coherent, non-meandering, orderly jet in quiescent fluid is possible only with appropriate chordwise flexibility of the flap.

During hovering, the vortex rings shed by the animal take the form of a jet of air blowing down vertically below the animal. This jet has thrust in downward direction, and thus it supports the weight of the animal by reaction [2]. The narrow, orderly jet produced by the flexible foil in still fluid during the present experiments is accompanied by a corresponding thrust. In a sense, this is a type of hovering, which is simple and different from the known hovering mechanisms present in the birds and insects.

The video showcasing all these flow-features is submitted to the *Gallery of Fluid Motion 2010* which is annual showcase of fluid dynamics videos. This video can be seen at the following URL:

Video.

## References

- [1] T. Maxworthy. *The fluid dynamics of insect flight*. Annu. Rev. Fluid Mech., 13, 329–350, 1981.

[2] M. J. Lighthill. *On the Weis-Fogh mechanism of lift generation*. J. Fluid Mech., 60(1), 1–17, 1973.